BART "DEAD TRAIN" DETECTION

Four students learned about one of the many difficulties which beset the start-up of the San Francisco Bay Area Rapid Transit system. They relate what they learned from interviews and add their comments and evaluation.

ECL 224

BART "Dead Train" Detection

A Case History

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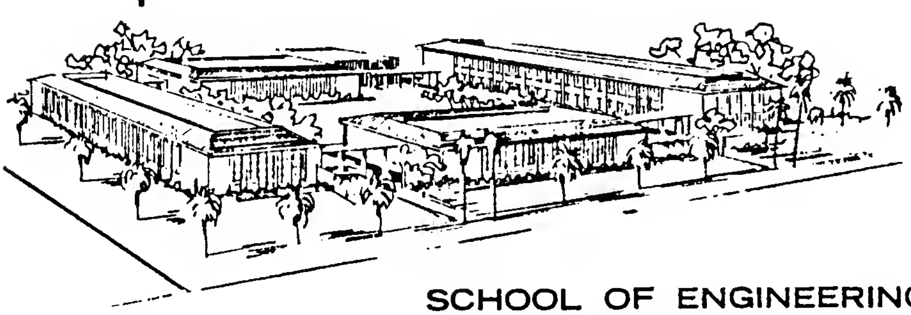

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As with any transportation system whether large or small, complex or simple, safety is an essential and uncompromising factor in the design and implementation. Yet safety is one of the most difficult requirements to define for any system. The concern of this paper is a safety-related problem of the San Francisco Bay Area Rapid Transit (BART). Specifically, the problem is one of train detection which is vital to the automatic train protection.

From its beginning, BART planned to operate trains by automatic means, not as a labor saving method but as an operating necessity: the control of high-speed trains (up to 80 mph) on close headways was beyond human ability to do so safely and consistently. Such a scheme must be able to detect train presence and position in relation to leading and following trains in order to maintain proper speed regulation and sufficient train separation. Detection is vital to passenger and train safety.

The train detection problem is not a hard problem to describe as an isolated and technical deficiency. But a discussion on the implications, the possible solutions, and the development of the problem is much more involved.

In order to fully understand the train detection problem it is necessary to explain how BART was conceived, how the automatic train control was developed, what tests and safeguards were set up and what these tests were lacking. It is necessary to go back to the beginning. And, for BART, the beginnings are in the late 1940's and early 1950's.

In the postwar era, the San Francisco Bay Area experienced an enormous growth in population. People came to the cities of the Bay Area looking for jobs and a place to live. What developed is the urban and suburban sprawl which makes up the greater San Francisco Bay Area. With that sprawl came the

rapid growth of automobile commuter traffic. Every working day, the cities of San Francisco, Oakland and Berkeley were the sites of a mass convergence in the mornings and a mass exodus in the evenings. The commuters came from the outlying areas of the eastern counties of Contra Costa and Alameda, from Marin County in the north and from San Mateo County in the south. Having no adequate alternatives, people commuted by private automobile, resulting in massive congestion on the freeways and in the cities.

The geographic features of the area, such as the Bay, limited access between major city centers, causing the bridges to become traffic bottlenecks. In 1947 the Navy Civil Engineering Corps and the Army Corps of Engineers recommended the construction of a transit tube beneath the Bay to alleviate the congestion. Studies predicted even more population and traffic growth. The only foreseeable solution was some type of large-scale, high-speed transit system. It would have to be something that would get the daily commuter out of his car.

In June 1957 the California State Legislature authorized the creation of the Bay Area Rapid Transit District (BART). The district originally included the five counties of San Francisco, Contra Costa, Alameda, San Mateo and Marin. (In 1962 Marin and San Mateo counties withdrew from the district under economic and public pressures.)

In May of 1959 the BART district retained three prominent engineering firms (Parsons, Brinckerhoff, Quade and Douglas; Tudor Engineering Company; and the Bechtel Corporation) to act as the general engineering consultants and contractors for a comprehensive rail mass rapid transit system. They were to operate as a single unit under the name of Parsons-Brinckerhoff-Tudor-Bechtel (PBTB). By 1962 PBTB had submitted its general proposal for BART. It was an ambitious plan that would take ten years to complete at an

estimated cost of one billion dollars.* This ambitiousness was expected, considering the scope of the problems it hoped to solve.

Thus, BART had its start as a saving solution to the Bay Area's traffic problems. Yet, before a single passenger revenue dollar was to be collected, BART was to face crisis after crisis of economic, political and technical problems. The financing of the one billion dollars presented a tremendous economic problem coupled with political and public opposition to the whole scheme.** The trans-bay tube and the seismic activity and the soil conditions of the area presented challenging problems to the structural and civil engineers. And, the concept of complete automatic train control was not without its problems. One such problem is the "dead train" detection problem.

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*In the three counties, the $762 million bond issue to be used to finance BART passed by a narrow margin of 1.2% over the required 60%.

**This is the estimated cost of the three county system.

The Test Track Program

The concept of automatic train control could not precisely be called novel. It could be said to have been unprecedented on such a large-scale. It should be noted that BART was the first rapid transit system to be constructed in North America in many years. Because of the lack of a market for new rapid transit equipment, manufacturers were not spending much on research and development of systems or equipment for rapid transit. Rapid transit technology was basically that of the 1930's, whereas in almost every other field of technology and engineering work there had been tremendous advancements. It was BART's objective to bring this improved technology to bear on the BART system. This was the philosophy behind the Test Track Program (1964-66) and behind PBTB's solicitation to more than 15 manufacturers to propose methods of fulfilling the general functional requirement for automatic train control. These requirements were fairly broad to allow the manufacturer to respond on a broad conceptual basis. More specific requirements would be drawn up after the test program. In fact, one of the objectives of the Test Track Program was to form a demonstrative basis from which PBTB could prepare the specific functional requirements for the ultimate system.

Seven firms replied to PBTB's solicitation. Of these, four systems were found sufficiently complete to warrant their demonstration in the Test Track Program. The four firms that participated in the program were General Electric Company (GE), General Railway Signal Company (GRS), Westinghouse Electric Corporation (WELCO), and Westinghouse Airbrake Company (WABCO).

As expected, since PBTB specified only functional requirements, the four companies presented diverse techniques with which to fill the general requirements. A brief overview of the competing control systems is shown in

Table 1, which has been taken from an article printed in Electronics Magazine, July 26, 1965. At this point, let it suffice to say that the four systems "successfully met the intents of the General Functional Requirements for these demonstrations". Yet, no one system was singularly outstanding and while there were successful demonstrations, "no single system fulfilled in entirety all the requirements for the BART automatic train control system".

The Test Track Program consisted of a series of tests which can be broken down into three categories:

Part I: "Normal circulation" tests in which the manufacturer demonstrated ability to operate the interlockings, to stop at stations, to control doors, reverse automatically, and to observe speed limits as required. If a contractor failed any test, he was allowed to check out the system, correct the problem and redemonstrate. Upon successful completion of all of these tests, Part II was started.

Part II: "Disrupt" tests. In these tests, willful safety violations were made, such as disconnecting all or part of the contractor's station-stop controls to test the ability to operate safely under these conditions. The presence of a train was simulated to check the enforcement of train separation. If these tests were completed satisfactorily, the "chase" took place. In the "chase" the car being tested was operated automatically behind a slow-moving car operated manually (except in the case of WELCO's demonstration in which the lead car operated automatically--manual operation on the main line was against the inherent properties of the system and would have shut it down). The lead car changed its speed and stopped in accordance with commands with the test coordinator to check for the safe response of the test car.

Part III: "Special" tests in which the contractor demonstrated special features of his system.

The test program served its purpose fairly well, though in hindsight may be viewed as being deficient in an aspect that might have led to the early

OVERVIEW OF COMPETING CONTROL METHODS

Company	Signal Technique	Blocks	Control	Carried on Train	On Wayside
General Electric Co.	Radar	Moving	Decentralized	Radar unit Analog computer Signal pickups	Transmission line Tuned coils at station approach Central computer (GE/PAC 4000)
General Railway Signal Co.	Audio frequency signals on rails	Fixed	Decentralized	Analog computer Signal pickups	Transmitters Receivers Tuned coils at station approach
Westinghouse Electric Corp.	Audio frequency signals on square wave wire loop	Fixed	Centralized	Audio generators Signal pickups Accelerometer	Square wave wire loop Wayside Controller (Prodac 50) Central computer (Prodac 500)
Westinghouse Air Brake Co.	Audio frequency signals on rails	Fixed	Decentralized	Analog computer Signal pickups	Transmitters Receivers Relay circuits Tuned coils at station approach Central computer (DDP-24)

TABLE 1

discovery of the "dead train" detection problem. Yet, the primary purpose of the test track program was more of a feasibility study rather than a system selection process. In fact, it was not necessary for a manufacturer to participate in this program to be eligible to compete in the bidding for supplying and installing equipment for the BART system. The reason for this was that not all companies interested in making bids would have been able to or would have been permitted to participate in the test program due to limited funds. (The test program was funded by a Housing and Home Finance Agency grant.)

From the results of the test program the Standard Specifications for the San Francisco Bay Area Rapid Transit were drawn up. Part J of the Standard Specifications concerns the automatic train control (ATC). Three very important articles of the Standard Specifications concerning train detection are quoted below:

Article J.6.3 — Train detection shall be employed to detect the presence of trains for train separation and route interlocking functions.

Article J.6.3.1 — Train detection shall detect the presence of trains throughout the entire revenue system. Trains shall be detected continuously. The maximum length of a train detection zone shall be 5,000 feet.

Article J.6.3.2 — If train detection equipment is incapable of detecting the presence because of momentary loss of signal or other conditions, the zone or zones which the train detection equipment is supervising shall be indicated as occupied.

Another article of the Standard Specifications stated that a detection system must be provided for protection against foreign vehicles or objects on the right of way.

As can be seen, these Standard Specifications are in the form of functional or performance specifications. It was left up to the contractor

to translate the performance specifications into hardware specifications. This was in keeping with the philosophy of the Test Track Program to allow diverse techniques and construction costs.

The BART District called for and received on February 28, 1967, competitive bids for the main line ATC and communications system. On March 16, 1967, PBTB recommended to the District that the ATC and communications contract be awarded to the low bidder, Westinghouse Electric Corporation. The low bid was $26,199,959.32.* The WELCO proposal that was approved by PBTB was quite different from the system WELCO demonstrated in the Test Track Program in 1964-1966. As stated before, participation in the test program was not a prerequisite for bid selection. One might say that PBTB's approval was "on paper", taking into consideration the merits of the proposal itself and WELCO's experience and test results.

It had been suggested by PBTB that a successful bidder be required to install his system on the test track and laboratory cars to demonstrate the successful operation of his system prior to the installation on the remainder of the system. Limited testing on the main line with laboratory cars was carried out.

The Westinghouse System

As mentioned previously, the system that BART bought was significantly different from the system WELCO demonstrated in the Test Track Program. Lower construction and maintenance costs were cited as reasons for the change. The following is a synopsis of that new system--how it should have worked and why it doesn't work:

The system employs the method of dividing the track into train protection blocks. Each block varies in length to a maximum of 1,200 feet. Each block is

*This was approximately $6.4 million dollars below PBTB's estimate. Yet, by July 17, 1973, change orders and escalation costs increased the cost to $34,943,176.53. The next lowest bidder was WABCO at approximately $29.6 million.

a track circuit loop formed by the running rails and heavy rail to rail bonding. A sketch of the track circuit is shown in Figure 1. At the ends of each circuit a transmitter, a receiver and a multiplexer were housed. Simply and basically, the track circuits perform two functions: (1) speed limit control and (2) train detection necessary to enforce power train separation. Each transmitter sends one of three audio frequencies (to distinguish adjacent track circuits) each with a digital modulation representing the speed command. The train equipment picks up the speed command from the rails through an inductive coil. The receiver at the other end of the block also picks up the signal, if it is present through inductive coupling. The transmitted signal is compared with the received signal at the local equipment room. If the signal comparisons agree, the circuit is assumed to be unoccupied. If a train is within the block, the steel wheels and axles will shunt the signal and the signal comparisons will not agree. The block is then considered occupied.

The train protection is provided by the local wayside equipment and not by the central computer. The maximum speed limit for each block is stored in the local equipment and it is also from this equipment that speed commands, enforcing proper separation, originate. The central computer performs the duties of scheduling and routing verification.

Tests prior to and after the opening of BART for revenue service in 1972 showed that the system worked fine if the train was detected. But, in the worst case, trains could not be detected. This is the problem of "dead train" detection. The worst case occurs when there is no power being supplied to the train and there is contamination on the rails (rust). Momentary loss of detection also occurs even with powered trains.

The wheel-to-rail, when there is contamination, take on the characteristics of a diode (see Figure 2). When there is power supplied to the train, the train-to-track potential exceeds the breakdown voltage of the rail contamination.

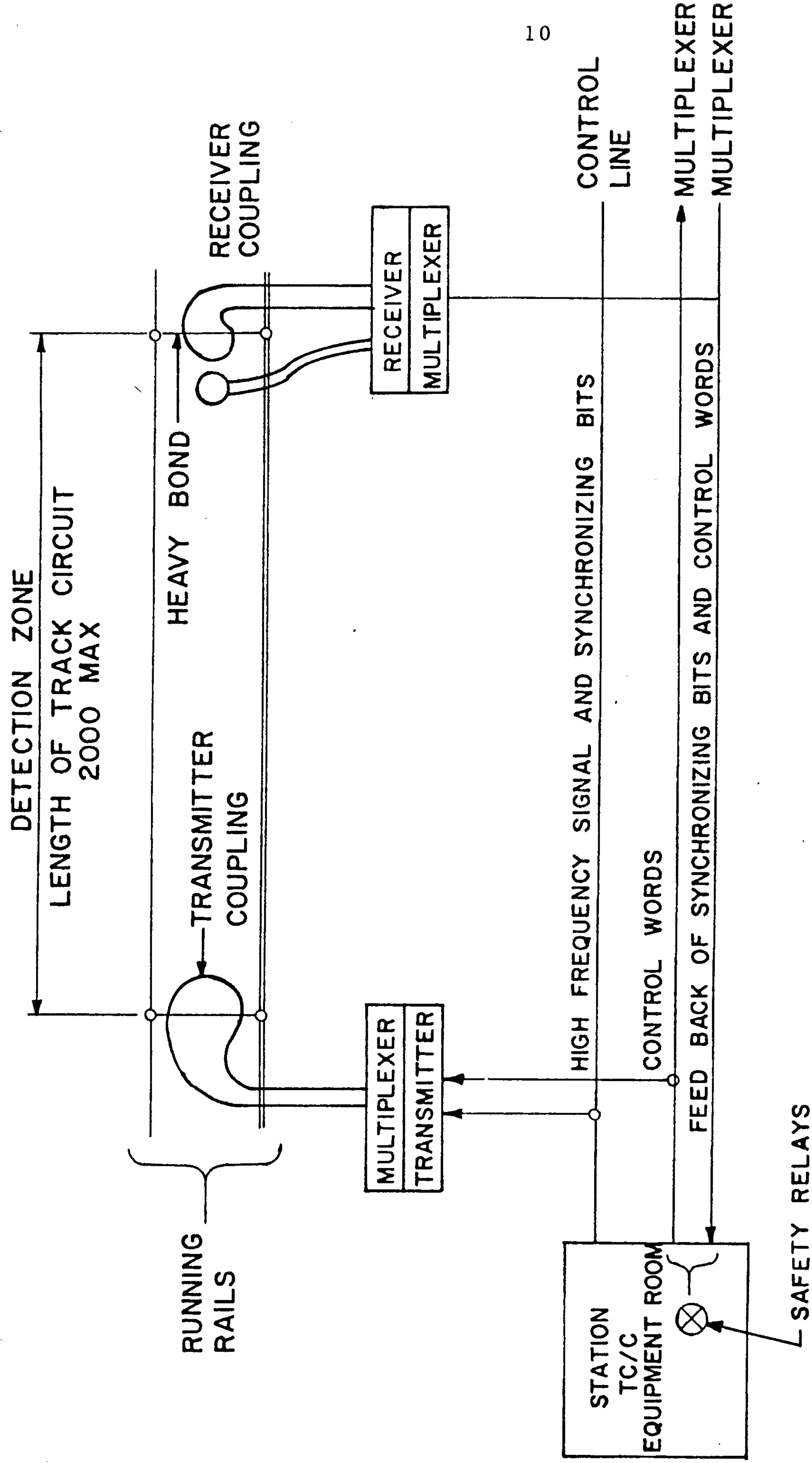

FIGURE I TRACK CIRCUIT AND CONNECTIONS SKETCH NO. I (COPY)

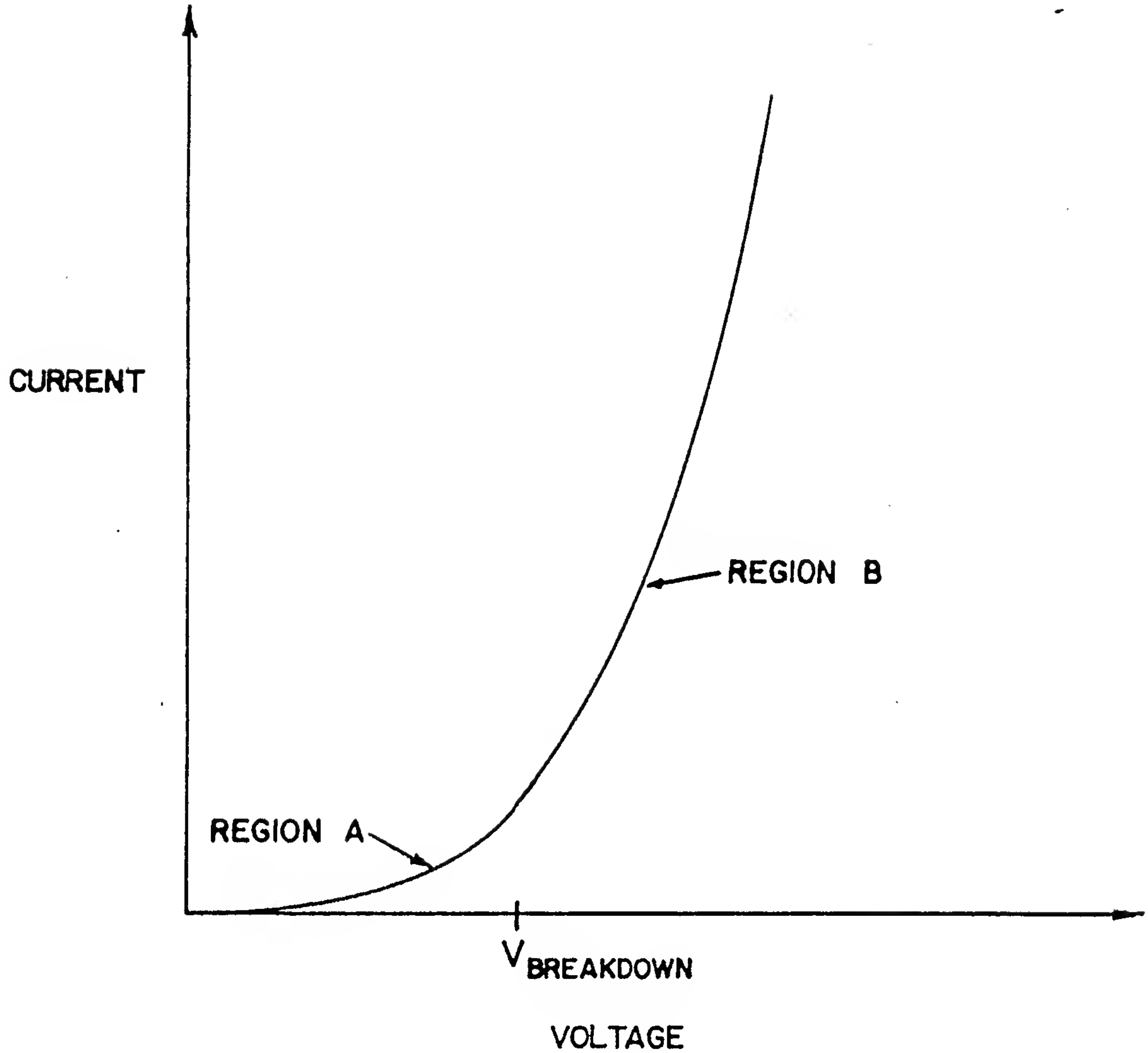

FIGURE 2: RAIL TO WHEEL IMPEDANCE CHARACTERISTICS

This breakdown of the contamination results in a low impedance and the control signal is shunted by the train. On the other hand, when there is no power to the train that is a "dead train", the contamination causes a high impedance. This may keep the control signal from being shunted which in turn causes this particular block to be labeled incorrectly as "unoccupied". As can be seen, this presents a potentially dangerous situation.

This "dead train" detection problem was discovered in 1971-72 just prior to the opening of the revenue service. In 1971-72 the Public Utilities Commission of the State of California (PUC), which has safety jurisdiction over BART, insisted that BART prove that the system could detect "dead trains". Tests were performed and BART failed.

The question now is: how could such a problem in a publicly funded project be overlooked by so many over such a long period of time (almost seven years)? The involved parties were Westinghouse Electric Corporation, Parsons-Brinckerhoff-Tudor-Bechtel, and the Public Utilities Commission. The result is a multimillion dollar law suit filed by the BART District against PBTB, WELCO, and others, not only for this particular defect but for others as well.

To begin with, in the Test Track Program, "dead train" detection was never performed. It was not a test consideration, even when a malfunction of WABCO's system, which is employed through the rail control signals, occurred due to rail contamination. It is our speculation that this evidence was ignored, "while WABCO was performing the disrupt portion of the qualifier with Car C, with the station-stop program disconnected, the car overshot the San Miguel CL station (as expected) but then <u>failed to shunt on the normally unused and rusty rails</u>. The car was stopped by the sand pile at the end of the track." Had the implications of this incident been fully explored, the "dead train" detection problem might have been corrected earlier.

This incident also did not seem to have an effect on the redesign of WELCO's system. Prior to the submission of bids to BART, WELCO redesigned their train detection system employing the principle of control signal shunting. We found no evidence that worst case analysis of train detection was studied.

The whole system of selection and testing prior to 1972 seemed deficient concerning rail contamination and "dead trains". The system of the successful bidder should have been tested prior to installation despite the time and cost restrictions. This may seem to be unrealistic, yet it may effectively be argued that safety considerations should not be limited by time and cost restrictions if there is any doubt about the design.

A safety analysis report done by Battelle Memorial Institute for PBTB was also deficient in this respect. This worst case analysis overlooked the effect of loss of power to the train and rail contamination, as PBTB and WELCO did. In fact, this report assumed detection and then proceeded to analyze the remainder of the ATC system.

Finally, the role of the PUC must be included. As a public transportation system, BART fell under the jurisdiction of the PUC for safety considerations. It was the PUC's function to regulate BART to insure that the equipment design, construction and operation be sufficiently safe. Since the BART system was unprecedented in California, the PUC had no existing regulations for automatic train control. The PUC therefore had to develop a set of regulations. The result was General Order 127 of the Public Utilities Commission of the State of California. This order was adopted on August 15, 1967, and became effective on September 15, 1967.

Section 2 of General Order 127 stated that "no train protection equipment or circuits in such equipment, which is part of an automatic train control

system, shall hereafter be constructed...until plans for such construction... have been filed with and approved by the Commission." When questioned on the point of Commission responsibility, a BART District official stated that General Order 127 did not go into effect until after the ATC contract was awarded. It does seem reasonable to assume that WELCO started design of its ATC before General Order 127 was established. The major part of the construction was done after the date that the PUC had adopted General Order 127 and it seems that the BART District did follow Article 2 of the general order after its promulgation.

In 1972 when the Public Utilities Commission was conducting final tests before letting BART commence operations, the failure of "dead train" detection was realized. This failure to pass the "dead train" test meant that the automatic train detection system would have to be revised before operations began because the worst case train protection had not been demonstrated to the PUC.

To prevent further delay of starting operations and thus increased political pressures, BART installed a manual block system. It was under this system that BART was opened to the public in 1972. This manual block system required BART personnel to be located at each station and in direct communication with the other personnel at the respective stations. This system allowed for an unsatisfactory 2 station headway. The procedure followed by station supervisors was, that when a train left a station that was two stations ahead of the trailing train, the supervisor would then call to the supervisor located at the station of the trailing train and then, and only then, would the trailing train be allowed to proceed.

The manual block system was in service for two years before mechanization of the system occurred. Since the central computer at Lake Merritt was receiving these occupancies and issuing door control commands, the fact that the central computer could accomplish the same objective as the supervisors became a reality. This system is called a Computer-Automated Block System (CABS). This system utilized the fact that a train cannot proceed unless its doors are closed. The central computer picks up the fact that the lead train (two stations ahead) has closed its doors and has vacated the occupancy. At this time, the central computer relays to the trailing train (two stations behind) that it may close its doors and proceed. This exact system was known as CABS-2. Later the system was refined so as to allow one station headways (CABS-1).

In order to achieve this new one station headway through the transbay tube, "ghost stations" were installed. M001 and M002, as these stations were called, consisted merely of circuits in the tube where occupancy could be established so as to allow the trailing train to enter the tube before the lead train had exited. M001 and M002 were located on tracks headed in opposite directions.

An obvious constraint to this system is that headways cannot be closed up to less than one station. This is true because the only place the central computer can exercise control over the trains is at the stations. Another disadvantage of the CABS-1 system was that if a train breaks down at some point or for any reason is delayed, the trailing trains are still required by central computer to maintain the one station headway, thus causing an eventual blockage of the line. This one station headway is opposed to a 90 second headway, dictated by the stopping distance required for the block.

In the short run, CABS-1 was an improvement over the manual block system but BART still planned to rely on the primary train detection system in the long run. As yet, the originally planned primary train detection is not

controlling train separation. A system is now being planned which will use the primary train detection system backed up by Sequential Occupancy Release (SOR).

SOR utilizes the principle that trains have to follow a logical, sequential pattern. This is a memory-type system that has mini-computers around 1,500 locations (blocks) as compared to the 34 of the CABS-1 system. If a train crosses a check point (mini-computer) for greater than one second, occupancy is memorized by the computer and not released until occupancy is confirmed several blocks ahead. This essentially is just an enlarged CABS system, but much more effective because the computer actually creates occupancy. Precautions have been taken for failure modes of the SOR as the system is more complex and computerized. The computer might memorize occupancy in the wrong block or fail to reset an occupancy after the train has vacated and cause a tie-up because of false occupancy. This increased accuracy is not without cost. The additional hardware and software increases the complexity and decreases the reliability.

BART officials are confident that the original train detection system, as modified by SOR, can be utilized for train separation. This in turn will serve to minimize headways. The primary systems along with SOR can achieve headways of 110 seconds, whereas the original primary system was to have brought headways down to 90 seconds. This 20 second difference is the result of the computer memorizing the occupancy and not resetting until the train is several blocks down the line. Since these computers do memorize occupancy, they provide additional safety during intermittent losses of detection.

In summary, the root of BART's ATC problems can be traced to unsatisfactory engineering design and test procedures. No one party can be held totally responsible. Rather, several involved agencies are responsible for completely overlooking the problem of "dead train" detection. Westinghouse Electric Corporation and Parsons-Brinckerhoff-Tudor-Bechtel, and the Public Utilities Commission of

the State of California all failed to consider the detection problem for a period of almost seven years prior to BART's opening in 1972. This was a serious oversight concerning the safety of the system and is reflective of poor engineering. It was only brought to light during qualification testing by the Public Utilities Commission of the State of California.

It is understood that in projects of the magnitude of BART there are constraints that limit engineering design. Politics and economics sometimes tend to oppose ideal safety conditions, yet all parties had a commitment to the public safety. The State's regulating agency is immune to economic pressures and it should insure the safe design and proper testing of the automatic train control. The PUC, although late in exercising its authority, did properly institute operating restrictions as outlined previously.

Arguments citing time and money constraints become meaningless when they relate to solving problems of such primary concern as the safety of a large number of passengers. Such problems must be resolved with subsequently larger expenditures of time and money. The time and monetary loss of supplementing the original design with the CAB and SOR systems has not been the only effect of this engineering inadequacy. More importantly, BART has suffered a loss of support not only from the professional ranks but also from the tax paying public and thus has negatively affected the movement toward a much needed large scale rapid transit.

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